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DEMONSTRATION & EVALUATION OF  
ALTERNATIVE TECHNIQUES FOR REDUCING  
HAZARDOUS FUELS IN SECOND-GROWTH  
PONDEROSA PINE FOREST NEAR RESIDENTIAL  
AREAS

~~Dr. Ronald Wakimoto~~



FINAL REPORT FOR RESEARCH AGREEMENT

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"Demonstration and Evaluation of Alternative  
Techniques for Reducing Hazardous Fuels in  
Second-Growth Ponderosa Pine Forest Near  
Residential Areas"

UNIVERSITY OF MONTANA

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**Reducing forest fire hazard in residential and scenic areas:  
a case study comparing three treatments in a western  
Montana ponderosa pine stand**

FINAL REPORT

RJVA #92685

Intermountain Fire Sciences Lab  
Steve Arno, ADOR

June 28, 1996

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## INTRODUCTION

Forest stands of ponderosa pine and Douglas-fir occupy thousands of acres of wildland in western Montana. Although ponderosa pine is found in pure stands on the driest forest sites, it is most commonly associated with Douglas-fir. On some sites ponderosa pine grows with lodgepole pine and western larch. Except in the pure stands on very dry sites, ponderosa pine is a seral species, eventually giving way to Douglas-fir and, on more moist sites, grand fir. Ponderosa pine forests have persisted in spite of this successional pressure because of its ability to survive the frequent, light surface fires much better than its would-be successors. Until the advent of effective fire suppression, ponderosa pine represented a "fire climax" on many sites that would otherwise succeed toward Douglas-fir or grand fir.

Although old-growth ponderosa pine/Douglas-fir stands were largely uneven-aged, current stands are mostly even-aged. This is a result of widespread logging around the turn-of-the-century followed by suppression of most subsequent fires. The mostly clearcut logging created ideal conditions for regeneration of even-aged stands, and the suppression of fire removed the disturbance that was largely responsible for creating the uneven-aged conditions in the old-growth forests. Most of these pine/fir stands have not experienced a fire in the last 75-100 years.

Ponderosa pine/Douglas-fir forests are readily accessible for human development, being the first (lowest) forest type encountered as one proceeds from the dry valley grasslands to the forested mountainsides. Moreover, many people find these forest stands to be very aesthetically pleasing. For these reasons there has been and continues to be much residential and recreational development in the low-elevation ponderosa pine-Douglas-fir forest type.

Unfortunately, these forests are quite flammable during the warm, dry summer months of most years. Whereas the fires of the last century were characteristically of low intensity and severity due to the frequency of such fires, the fires likely to be experienced in this type today are much more severe. During the 75-100 years since the last fire in many of these stands, at least three significant changes have taken place which lead to this increase in severity. One is that the quantity of accumulated dead and down fuels in

these forests has increased. The frequent fires of before served to keep these fuel level low, by consuming the majority of it during fires every 5-25 years. Without these frequent fires, fuels continue to accumulate faster than decomposition. This accumulation of fuels is likely to continue or even accelerate as the stands get older and experience increased mortality. The second change is an increase in stand density resulting from fire suppression. The frequent fires of the past thinned the forest lightly, thereby keeping the density low and allowing more space between trees. Today's dense forests are more tightly packed, leading to an increased risk that a fire will spread from tree top to tree top uncontrollably. The third change leading to increased fire severity is the establishment of a shade-tolerant conifer understory of Douglas-fir or grand fir. These small trees represent a "ladder" which allows a fire to climb from the surface into the crowns of overstory trees. Once a fire has developed into a "crown fire" it becomes very destructive and nearly impossible to stop.

Fire hazard in ponderosa pine stands can be lessened by prescribed burning, removing the understory fuels, pruning lower branches of small conifers, and by thinning the trees to lessen the likelihood of a crown fire. In several cases in the western United States, severe wildfires have been stopped after reaching areas treated with prescribed burning or other hazard reduction treatment. Such treatments generally keep the fire from spreading into tree crowns, making fire suppression more effective.

The simulated behavior of a hypothetical wildfire in the area surrounding a forest home provides an index of the difficulty of suppressing a fire and protecting a structure. Fires exhibiting flames less than about 4 feet long can generally be directly controlled with hand tools. Fires with flame lengths between 4 and 11 feet can often be controlled with more aggressive tactics such as the use of bulldozers and fire retardant to construct wide firelines. Fires with flame lengths greater than 11 feet are very difficult to control and, under a timber stand, frequently lead to crown fires. From a structure protection standpoint, potential flame lengths should ideally be reduced to the level at which hand tools can be used to control the fire.

Whether the fire hazard reduction treatment is to take place on a wildland residential property or in a recreation area, effects of the treatment on visual quality of



the stand are of great concern. Studies have shown significant differences in perceived scenic beauty between silvicultural systems (Benson and Ullrich 1981). In general, scenic quality of forest stands is directly related to factors such as tree size and inversely related to the amount and arrangement of woody fuel and the presence of stumps and other indicators of logging activities, among others (Daniel and Boster 1976). The presence of black char on bark resulting from prescribed fires is aesthetically undesirable. It is likely that the scenic quality of the stands will change after treatment because all of these factors are affected by the treatment. However, the magnitude and direction of such change is difficult to predict. Negative changes in aesthetic quality resulting from a commercial logging operation can be minimized by using techniques like cutting stumps very low to the ground and reducing ground disturbance by logging over snow or using smaller equipment.

Many homeowners recognize the need to manage fuels on their forest properties. However, their concerns about the cost of reducing fuels to acceptable levels and about the potential negative effects on aesthetics often prevent action. Hazard reduction treatments like pruning and prescribed burning generate no income and can therefore be quite costly. If combined with a thinning operation, however, the sale of forest products could offset most or all of the cost of reducing fire hazard. Other benefits of thinning to reduce fire hazard can include a healthier, more vigorous stand, reduced crown fire hazard, and better likelihood of tree survival in case of a fire.

## **PROBLEM STATEMENT**

The high aesthetic quality and accessibility of low-elevation ponderosa pine/Douglas-fir stands gives them a high social value for recreation and residential development. Since this value depends largely on the aesthetic value of living trees in the forest, this value is at risk of damage from the severe wildfires capable of occurring in this forest type. Therefore, management of public and private land with high social values should attempt to minimize the risk of severe wildfire while maintaining the high aesthetic values.

Standard hazard reduction treatments such as thinning and prescribed burning have been designed and implemented largely for commercial forestland, where aesthetic concerns are fewer and occur at a different scale (far-view as opposed to near view). Private landowners and other concerned members of the public are often wary of the Forest Service attempts to apply hazard reduction treatments, especially thinning, to high value recreational areas. Private landowners also seem to be concerned about applying such treatments on their own land.

Hazard reduction treatments in visually-sensitive ponderosa pine/Douglas-fir forests will be necessary to protect the quality of these forests in the long term. Because there are few precedents for applying hazard reduction treatments in residential and recreational settings it is difficult to gain the public support necessary to successfully implement such treatments.

To effectively manage visually-sensitive ponderosa pine stands to reduce fire hazard in western Montana, Forest Service managers and wildland homeowners need basic descriptive information (guidelines) and a demonstration of such treatments to reduce fire hazard in a ponderosa pine stand. These would clarify the degree to which different fire hazard reduction treatments actually reduce the threat of fire, document any change in visual quality, and estimate the cost/revenue of conducting the treatments.

## OBJECTIVES

- (1) Develop and implement three contrasting silvicultural prescriptions to reduce fire hazard and improve forest health in visually-sensitive second-growth ponderosa pine forests.
- (2) Quantitatively compare the three treatments in terms of potential fire behavior, visual quality, and cost feasibility.

The general objective of this study is to develop, demonstrate and compare three contrasting techniques for reducing hazardous fuels in ponderosa pine stands in residential, recreational and scenic areas of western Montana. The on-the-ground demonstration and related descriptive information will allow fire officials, land use planners, forestland developers, public land managers and wildland homeowners to compare adjacent units of initially-similar forest that have been treated in different ways to reduce the threat of a wildfire. The aesthetic quality of each treatment unit will be quantitatively compared using TRIADS as well as other methods.

Descriptive summaries of fuel loadings, predicted fire behavior and crown fire risk will be computed. Crown fire risk will be evaluated by comparing the ratio of predicted surface fire flame length to the critical flame length required for crown combustion (following Van Wagner 1977).

Similarly, the revenue generated by the different treatments and associated costs will be tabulated. Net cost/revenue will then be expressed on a per acre basis.

Due to limited area of homogeneous stand in the study area it was not possible to replicate the treatments. Therefore, it is not possible to statistically compare the different treatments in terms of fire behavior or treatment costs. However, for the purpose of providing a demonstration, descriptive statistics will suffice. Also, because the three treatments will vary in more than one factor (residual basal area, thinning method, equipment type and slash treatment), this study should be viewed as a case study rather than a traditional experiment involving the investigation of a single factor. This case



study is designed to demonstrate viable (realistic) yet contrasting treatment alternatives to professionals and to the general public. This study's purpose is not to determine how each individual treatment factor affects visual quality, fire behavior or economic feasibility.

## STUDY AREA

The study area is located in the Sixmile Creek drainage of the Ninemile Ranger District, Lolo National Forest, about 30 miles west of Missoula, Montana (Figure 1). Representatives of the Ninemile Ranger District, the Intermountain Fire Sciences Lab and the University of Montana School of Forestry selected the study area after visiting four possible sites on the ranger district. The area is covered by a dense stand (140 square feet per acre basal area) of young-growth ponderosa pine/Douglas-fir, with Douglas-fir constituting a minority of the total basal area (Figure 2). Western larch is present but rare in some of the treatment units. Dominant trees in the stand are generally 100-150 years old, although a few scattered old-growth ponderosa pines are found throughout the study area. The many large, old stumps throughout the area, most of which bear multiple fire-caused wounds, were created when the area was first logged in the late nineteenth century.

A count of the fire scars on several of these old stumps in the area indicates that individual trees recorded as many as 21 fires. Because any individual tree often fails to record all fires that burned in a stand, we would expect that fire occurred even more frequently than suggested by these individual tree counts. Unfortunately, the stumps are too rotten to permit tree ring counting and cross-dating, which would enable construction of a master fire chronology. Historical fire records and the lack of fire scars on trees that established following the early logging indicate that there may not have been any fires in this stand for more than 100 years.

Slopes within the study area are generally south-facing and incline 5-20%. The study area is at 4000 feet elevation. Habitat type over most of the study area is *Pseudotsuga menziesii*/*Physocarpus malvaceus*, *Calamagrostis rubescens* phase (Pfister and others 1977). This habitat type falls in Fire Group Four, warm, dry Douglas-fir habitat types (Fischer and Bradley 1987). Ponderosa pine is a seral species on these habitat types, but frequent fires prevented succession toward a Douglas-fir forest. However, with continued fire exclusion these stands will succeed toward the Douglas-fir climax as the

ponderosa pine overstory dies out (Fischer and Bradley 1987) and is replaced by the advanced regeneration of Douglas-fir.

The stands in the study area are even-aged and even-sized. The modal diameter at breast height is approximately 8 inches for both ponderosa pine and Douglas-fir. There are very few trees of either species less than 3 inches in diameter at breast height, not including advanced regeneration of Douglas-fir. The maximum tree diameter is 23 inches for both ponderosa pine and Douglas-fir. Understory vegetation is composed mainly of grasses (dominated by pinegrass), shrubs such as snowberry, kinnikinnick, ninebark and serviceberry, and a small amount of Douglas-fir regeneration.

## METHODS

To meet the first objective of the study, three treatments for reducing fire hazard in visually-sensitive ponderosa pine stands have been developed for the stand conditions found in the study area. The main requirement of any fire hazard reduction treatment is to reduce crown and ladder fuels enough to prevent the possibility of a crown fire. It is also desirable that the treatments generate enough income to offset all of the costs of implementing the treatment. Therefore, all treatments involve a commercial thinning operation designed to reduce crown fuels and improve tree vigor by reducing the number of stems. The treatments vary in the harvesting method, slash disposal method, residual basal area, and guidelines for selection of leave trees (thinning method). Treatments that do not involve thinning (such as understory removal, pruning, or prescribed burning) were not considered because of the importance of reducing crown fuels to minimize crown fire risk and because the high cost of conducting these treatments makes them unfeasible for most national forest and private land.

The prescribed treatments were designed around three contrasting "themes", or emphases, within the overall treatment goal of reducing fire hazard and improving forest health. The three alternatives respectively emphasize: forest health, short-term income and minimum visual disturbance. Details of the three treatment prescriptions are as follows:

### Forest Health

**Objective/emphasis:** Reduce fire hazard, improve stand health (vigor), restore "natural" conditions (the conditions that would likely have developed under a continued regime of frequent surface fires) using thinning to mimic natural fires and by applying prescribed fire.

**Residual Basal Area:** 75 ft<sup>2</sup>/ac. Forest history studies indicate that ponderosa pine stands probably carried less than 75 ft<sup>2</sup>/ac basal area. However, no more than half the



initial basal area should be removed in a single entry to minimize risk of wind damage to the residual stand. Therefore, the basal area was reduced from 143 to 75 ft<sup>2</sup>/ac.

**Marking rules:** The unit will be thinned from below (low thinning). The largest and healthiest trees (dominants and co-dominants) will be retained to create an open "park-like" stand. Mainly suppressed and intermediate trees will be removed. Dominant and co-dominant trees will be harvested only as necessary to reduce basal area to target and to space crowns. Trees with defects, insects or disease will be marked for removal except to fulfill the wildlife habitat requirements. Douglas-fir will be removed whenever possible to favor a ponderosa pine overstory.

**Wildlife Habitat:** Approximately 1 tree per acre with potential for providing bird habitat (large trees with dead top, forked top, gnarled branching, *etc.*) will be retained.

**Harvest:** Harvest may be done with conventional rubber-tired skidding equipment. A tracked feller-buncher may be used. Tree may be skidded to the landing with branches attached to the logs but the top must be left in the woods. Alternatively, the trees may be skidded tree-length to the landing if at least half of the slash is "back-hauled" and distributed in the woods. The purpose of the slash handling requirements is to ensure that nutrients contained within the branches are not removed from the stand.

**Slash:** The stand will be broadcast burned to reduce the light slash (tops) and natural fuels, and to maintain a natural forest undergrowth. The objective of the fire is to consume most of the needle litter, 1- and 10-hour fuel components. Slash and existing 100- and 1000-hour fuels should be reduced by approximately 50%. The slash pile generated at the landing will be burned when safe to do so.

## Generate income

**Objective:** Generate income from the sale of forest products while reducing fire hazard and improving stand vigor.

**Residual Basal Area:** 75 ft<sup>2</sup>/ac Forest history studies indicate that ponderosa pine stands probably carried less than 75 ft<sup>2</sup>/ac basal area. However, no more than half the initial

basal area should be removed in a single entry to minimize risk of wind damage to the residual stand. Therefore, the basal area was reduced from 143 to 75 ft<sup>2</sup>/ac.

**Marking rules:** The unit will be thinned from above (high thinning). Dominant and co-dominant trees are harvested to release trees of those same classes. Crop trees (those which will remain after harvest) are mainly the dominant and co-dominant trees, with a few "specimen" old-growth trees retained. Douglas-fir will be removed in preference to pine.

**Wildlife habitat:** Approximately 1 tree per acre with potential for providing bird habitat (large trees with dead top, forked top, gnarled branching, *etc.*) will be retained after harvesting. **Harvest:** Trees will be tree-length skidded using a rubber-tired skidder to a central landing, where the tops and limbs will be piled by machine and burned when safe to do so. A feller/buncher may be used in this unit.

**Slash:** The slash pile will be burned in the spring. No further fuel treatments will take place on the unit.

### Minimum Disturbance

**Objective:** Reduce fire hazard and modestly improve stand vigor with minimal impact on the visual quality of the stand.

**Residual Basal Area:** 100 ft<sup>2</sup>/ac. At this level of residual basal area, the risk of crown fire should be reduced without significant visual impact.

**Marking rules:** The unit will be thinned from below (low thinning). The largest and healthiest trees (dominants and co-dominants) will be retained by thinning mainly suppressed and intermediate trees. Dominant and co-dominant trees will be harvested only as necessary to reduce basal area and space crowns. Trees with defects, insects or disease will be marked for removal except to fulfill the wildlife habitat requirements. Douglas-fir will be removed whenever possible to favor a ponderosa pine overstory.

**Wildlife habitat:** Approximately 1 tree per acre with potential for providing bird habitat (large trees with dead top, forked top, gnarled branching, *etc.*) will be retained after harvesting. **Harvest:** Trees will be bucked into short logs (maximum 26'2"), topped and

delimbed in the woods and skidded by a 50-horsepower farm tractor to a roadside deck. No landing space will be created.

**Slash:** Slash and some existing fuels will be piled by hand and burned when safe to do so. Progressive pile burning may also be used.

A traditional experimental design would entail isolating the effects of one or more factors (residual basal area, equipment type, different levels of burning, type of thinning, etc.) while holding all other factors constant. Such a study could determine, for instance, the residual basal area most acceptable to the public in terms of visual quality, or the minimum treatment necessary to reduce fire hazard to a given level. However, because of limited area of homogeneous stand in the study area for replication of treatments, it was decided to design and study a small set of treatments that address the above factors in realistic combinations. The results of this type of study must be carefully interpreted. This approach can lead to significant confounding of results, because the outcome of a treatment cannot be attributed to any single factor. For example, if the minimum impact treatment is preferred over the others, in terms of visual quality, it may be due to the higher residual basal area, the lack of broadcast burning, or the nature of the harvest method.

Four 6-acre treatment units were established within the study area, one for each treatment plus an untreated control unit (Figure 3). The units are rectangular, 750 feet long by 350 feet wide and oriented such that the long axis runs up and down the slope wherever possible. This unit size was chosen because a large area is needed to effectively measure impacts on stand esthetics. Evaluation of the esthetics of a small treatment unit is difficult because so much untreated stand is in view.

Because the three treatments will not be replicated, this research will essentially be a case study in which the "cases" (i.e., treatments) are controlled. A block design could not be used because a 24-acre patch (1500 x 700 feet) of homogeneous stand could not be placed anywhere in the study area. The study design used here is similar to a single block (one replication), but the units within the block are not directly adjacent. An untreated control unit was established so that pre-treatment conditions can be

monitored through time and compared with the treated units. For demonstration purposes, this is required to show how the stand appeared before treatment.

Ten sampling points were systematically located within each treatment unit (Figure 4) to measure stand structure and fuel loading. Sampling points were permanently marked with a 12-inch nail driven flush with the ground and a wire stake flag bearing the unit and plot designation. Two numbered aluminum tags were nailed to the base of two trees near each sample point to aid in relocating plots after treatment. The sample point layout is shown in Figure 5.

Each unit was assigned to one of three treatments (four including the untreated control). The following unit assignments now apply:

- Unit 1: Minimum impact treatment
- Unit 2: Generate income
- Unit 3: Forest health
- Unit 4: Untreated control

The remainder of the methods section deals individually with the three considerations laid out in objective 2, namely (1) perception of visual quality, (2) potential fire behavior, and (3) net cost/revenue of carrying out the treatments.

### **Visual quality**

Five forest conditions were evaluated for scenic beauty. Four of the conditions are simply the four treatments (including the untreated control) at the Sixmile Demo Study Site. A fifth condition was added for comparison -- a stand of pine and Douglas-fir, very much like those in the study area. However, the fifth condition experienced a severe underburn during a broadcast burn in the Spring of 1995. Mortality was significant in the overstory, but understory vegetation recovered well. After the fire, some trees were salvaged for sawlogs and firewood. This condition was added to the analysis because it represents the likely condition of these pine forests after a wildfire. Therefore, it can be viewed as an alternative "control".

A common method of comparing the visual quality of different areas is the Scenic Beauty Estimation (SBE) method (Daniel and Boster 1976). With this method, a panel of viewers is assembled to rate color slides of the treatment units on a scale of 0-9. The raw scores are then transformed and standardized to account for differences in the way different viewers use the scale, allowing the computation of a rating for each area. Unfortunately, this method is very time-consuming. Moreover, the SBE method usually does not do a good job of distinguishing between very similar treatments (Benson 1995). Since the treatments used in this study are similar to one another (all commercial thinnings), the SBE method is likely to show no significant difference between treatments.

Other studies in the ponderosa pine type have shown that certain features of the scene can be used to predict the scenic beauty of an area without going through the viewer rating panels.

An alternative visual quality analysis method called photo TRIADS was used to compare the treatments because it forces the person doing the rating to pick treatment preferences from sets of three photographs. A total of 28 viewers were shown 10 sets of photos, three photos per set. Photos were arranged so that each treatment was paired with every other treatment. Viewers were asked to view each set and decide which scene they preferred most and which they preferred least, for each set of photos. A scene which was judged "most preferred" was chosen over two other scenes and was given a score of 3. The intermediate scene (not ranked most or least preferred) was preferred over one scene and was given a score of 2. The least preferred photo was given a score of 1. The treatments could then be ranked by preference by summing the scores over all viewers and sets, providing a total vote count (Coombs 1964). This method will rank the treatments by viewer preference, but will not provide a good indicator of the magnitude of the preference. Therefore, visual quality was assessed using both the SBE metrics and TRIAD methods.

To make a long-term record of the visual changes taking place following treatment six permanent photo points have been systematically established in each unit (Figure 6). Color slides were made before and after treatment. Additional slides should be made at roughly 2-3 year intervals to document longer-term changes.



Robert Benson of Systems for Environmental Management conducted the visual quality analysis reported here (Benson 1996) under a separate agreement with the Intermountain Fire Sciences Lab.

### **Potential Fire Behavior**

Fire behavior is a function of fuels, topography and weather. Topography (slope and aspect) is not modified by thinning or prescribed burning. Weather conditions can be modified by thinning if the canopy is reduced enough to allow increased windspeeds and increased insolation. Since all treatments implemented in this study are light thinnings, the effect on fire weather should be small. The fire hazard reduction potential of these treatments arises primarily from modification of the quantity of available fuel. Therefore, the loading of dead and down (1-, 10-, 100-, and 1000-hour timelag classes), herbaceous, shrub, litter and crown fuels was measured before and after treatment, and on the control unit. Surface fuels were inventoried using the planar-intercept method (Brown 1974). One permanent fuel transect was established at each of the 10 sample points in each unit. The sample point nail marks one end of the transect, and the other end is marked with a 12-inch nail driven flush with the ground. The 1-, 10-, 100- and 1000-hour timelag fuels were sampled along transects which are 6, 6, 10, and 40 feet long, respectively. The slope of the sampling plane was recorded in percent to the nearest whole percent. The diameter of fuel particles greater than 3 inches in diameter which intersect the sampling plane was recorded to the nearest 0.1 inch as "sound" if the particle fell apart when kicked or as "rotten" if the particle did not fall apart when kicked. The distinction between sound and rotten logs is made because the specific gravity varies considerably with the degree of decomposition.

Duff depth was measured and recorded in inches to the nearest 0.5 inch at points on the transect 30, 34 and 40 feet from the sample point. The depth of the highest fuel particle intersection (including grasses, forbs and shrubs) was measured in inches to the nearest inch along three one-foot lengths at the far end of the fuel transect (Brown 1974). The sampling plane was oriented such that the fine fuels were sampled on the end away from the plot center to avoid the disruption of the fuelbed which may occur at

permanent sample point centers. The orientation (true azimuth) of the transects at each plot is shown in Table 1.

Herbaceous (grasses and forbs, both live and dead) matter and needle litter fuel load was estimated using the relative-estimate method (Brown and others 1982) at each sample point. Four subplots (1.0 foot by 1.0 foot wire frames) were placed systematically at the end of the downed woody fuel transect (Figure 3). The four subplots were ocularly examined to determine which subplot appeared to contained<sup>ed</sup> the greatest weight of live and standing dead herbaceous matter (dead, matted herbaceous matter is considered litter). The subplot with the highest apparent weight of herbaceous matter became the standard herbaceous subplot, and was recorded as "100" in the "percent of standard" column on the data sheet. The remaining subplots were reexamined to ocularly estimate the percentage, by dry weight, of herbaceous matter on each subplot relative the standard, to the nearest 5 percent.

Weight of conifer needle litter was measured using the same relative estimate procedure as for herbaceous fuel. Dead grasses which have become matted by snowfall were considered litter. Dead grasses which were still standing and attached to a stalk in the ground were considered herbaceous matter.

Litter and herbaceous matter was then collected from the proper standard subplot and placed in a paper bag labeled with the unit, plot, subplot, and whether the bag contained litter or herbaceous matter. The bags with their contents were dried in a drying oven at 95-100 C for a period of 24 hours. Ten empty paper bags were also oven-dried and weighed to determine the average tare weight of the paper bags. The weight of bags with their contents was recorded to the nearest 0.01 gram on the proper data sheet. A ceramic plate was placed on the electronic balance prior to measurements to prevent heat transfer to the balance, which could affect the accuracy of measurements.

Each subplot was examined for the presence of shrub stems. Where present, stems were recorded by subplot number, species and basal diameter class. The number of trees between 1 and 4.5 feet tall was tallied by species on a circular 1/300 acre plot (6.8 feet radius), centered on the end of the fuel transect (Figure 5).

The number of trees greater than 4.5 feet tall were tallied by species and two-inch diameter class (0-2 in, 2-4 in, *etc.*) on a 1/10-acre circular plot (37.2 feet radius) centered on each sample point (Figure 5). Crown bulk density, used in the analysis of crown fire potential, was computed using the DBH/crown weight regression equations developed by Brown (1978).

This complete fuel (biomass) inventory was repeated following treatment in order to measure changes in the fuel complex which might affect fire behavior. Following the treatments, stand structure was more accurately measured by measuring the diameter of each tree on the 0.1-ac plots to the nearest 0.1 inch. The height the base of the live crown was estimated and recorded at each of the sample points.

At the same time the trees were measured for diameter, they were also inspected for the presence of logging scars, bark char and recent bark beetle attacks. Scars on trees from this logging operation were recorded as none, small, medium, or large. Depending on the size of the wound. If the bark was undamaged or scraped but still left intact the trees was recorded as "none" for logging scars. The tree was recorded as having a small scar if the cumulative area of cambium exposed by recent this logging was less than about 10 square inches on a tree. A cumulative area of more than one square foot was considered a large scar. In between 10 square inches and one square foot was a medium scar.

Bark char was subjectively recorded for each tree as light, medium or heavy after considering the height and depth of charring on all sides of the tree.

Bark beetle attacks (including attacks of the Douglas-fir beetle in large Douglas-fir) was subjectively recorded as light, medium or heavy depending on the number and apparent success of the attacks on the tree. Trees rated with light attacks are almost sure to survive the attack, whereas trees rated as having heavy attacks are likely to die. Trees rated with medium could go either way, but will likely survive if healthy and not additionally stressed by drought or other factors.

The crown fire risk on each unit was assessed using Van Wagner's (1977) theoretical model, which calculates the critical fireline intensity (or flame length) of a surface fire necessary to initiate crown combustion given characteristics of the canopy.

Similarly, a critical surface fire rate of spread must be exceeded to maintain an active or independent crown fire.

### **Economic Feasibility**

The net cost/revenue of conducting these treatments was computed using the harvest volume determined by the timber cruise, published and estimated data on logging costs, and the actual cost of additional treatments, such as prescribed burning. Total revenue from each unit was computed by multiplying the volume of logs in each unit by the most recent log prices reported by the Bureau of Business and Economic Research (1995) at the University of Montana. For each unit, the weighted-average delivered log price was determined using the timber cruise information. Log volume harvested by species was taken from the Forest Service timber cruise which formed the basis for each unit sale.

The net revenue for each treatment was calculated as the difference between total revenue and total cost. Potential future monetary or non-monetary benefits such as a decrease in the expected value of wildfire damage to a structure was not considered. This case study reports only the immediate-term monetary costs and revenue.

## RESULTS

The treatments laid out and marked as prescribed. However, the harvesting could not occur until the spring of 1993, due mainly to the commercial logging contractor's schedule. The logging contractor for the minimum-impact unit attempted to conduct the harvest in that unit earlier in the winter, but was thwarted by heavy snowfall.

The slight delay in getting the units logged meant the broadcast burn in unit 3 was pushed back from the spring to fall of 1993. Thus, the 1993 growing season was lost as a season of post-fire vegetative recovery. This meant that the entire time line had to be pushed back one year, in order to ensure that two full growing seasons of vegetative recovery had taken place before the visual analysis.

Table 2 indicates that the residual basal area targets were achieved in each unit with a reasonable degree of accuracy. The basal area target was very precisely achieved in unit 3, but a little too much was harvested from units 1 and 2. The accuracy achieved in this study is in line with what can be expected from an operational treatment. This table also indicates that while the untreated control (unit 4) was a little more dense than the others, it is close enough to provide a good demonstration of initial stand conditions.

The average stand diameter was increased after treatment in all units (Table 2), due mainly to the fact that the thinnings were generally from below. The smallest increase in average stand diameter was in unit 2, which was thinned from above. Even though thinning from above, enough small (probably poor quality) trees were harvested to increase the overall stand diameter. Treatment 3 showed the largest increase in average stand diameter (from 10.4 to 13.3 inches) because it was thinned from below with moderate intensity. The increase in average stand diameter for unit 1 was intermediate between units 2 and 3.

Inspection of each tree in the 1/10-ac plots reveals significant differences between the units in terms of scarring, bark char and beetle attacks. The minimum impact treatment experienced no logging scars at all, whereas about 25% of the trees received at least a small scar in units 2 and 3 (Table 3). It is difficult to use a feller-buncher and tree-length skidding without causing scarring with residual stand densities such as these,



especially if no special precautions (like making wider skid trails) are made when marking the treatment. Logging scars, especially on Douglas-fir and larch, often lead to disease and bole rot, reducing future timber values.

There was no bark char in unit 2, since there was no burning to take place there. Unit 1 had a very small amount of light char, caused by one of the hand piles. In unit 3, 93.6 percent of the trees had some amount of bark char, most of that was rated medium. Only 18 percent of the trees had heavy bark char. Bark char has negative implications for forest aesthetics, and may indicate cambium damage which leads to fire scar formation. Basal heat damage to pines, indicated by bark charring, may increase the length of time the tree remains standing after it eventually dies, improving its value for wildlife. Trees with light or medium bark char probably did not significantly damage the living cambium of the tree, and represent only an aesthetic problem.

All units, including the control, experienced some degree of bark beetle activity. Not surprisingly, the burned unit 3 had the highest level of beetle activity. The minimum impact unit 1 had the next lower level of activity, followed by unit 2 and the control unit. Some degree of beetle activity usually occurs in all pine stands. Activity usually increases following harvesting and especially burning. Most of the activity in the treatment units resulted in trees being only lightly attacked (Table 3), so there should be little mortality. Only in units 3 and 1 were many trees heavily attacked. Some beetle activity should be expected following a thinning and burning treatment in a pine stand, and this should ideally be considered when figuring a target residual basal area.

### Visual Quality

Using the triad method of analyzing scenic beauty, the fire treatments were ranked by total vote count as follows:

| <u>Treatment</u>               | <u>Total Vote Count</u> |
|--------------------------------|-------------------------|
| Treatment 1 (Minimum Impact)   | 384                     |
| Treatment 2 (Generate Income)  | 345                     |
| Treatment 4 (Unburned control) | 332                     |
| Treatment 3 (Forest Health)    | 317                     |
| Treatment 5 (Burned Control)   | 302                     |

By this ranking, treatment 1 was ranked as having the highest aesthetic quality, whereas treatment 5, the severely burned area was ranked the lowest. However, the ranking confirm that there appears to be strong similarity among treatments making strong preference distinctions difficult. This is tested by examining the transitivity of the preferences, or how often the preferences were "reversed". For example, although Treatment 1 was ranked higher than Treatment 2 in the overall ranking, sometimes (some viewers) Treatment 2 was preferred over Treatment 1. Of all individual preferences made, 59% were in agreement with the overall ranking shown above while 41% were intransitive. This indicates that there were not sharp differences in preference -- reinforcing the notion that all treatments were aesthetically similar.

Scenic quality of the treatments was also analyzed with the Arthur's (1977) physical features model, since this model most closely reflected the rankings shown by the Triad analysis. This model<sup>s</sup> predict<sup>v</sup> the visual quality of the treatments from features of the scenes, such as tree size, stand density, grass/forb cover, and slash. None of the available models has bark char as a variable so they may not accurately rank these treatments, some of which included fire.

The Arthur physical feature model predicted the scenic beauty would rank in the same order the treatments were numbered, coincidentally. That is, Treatment 1 was ranked highest, Treatment 2 the second-highest, and so on. The only difference between these rankings and those of the Triad analysis is that the rank of Treatments 2 and 4 are switched.

For more detailed information on these and other scenic quality analyses of the Sixmile treatments, including a comparison with other studies, see the report by Robert Benson on file at the Intermountain Fire Sciences Lab.

## **Potential Fire Behavior**

### **Surface Fire**

The loading of live and dead fuels by class, both before and after treatment, is shown in Table 4. Treatment 4, the control, is was measured only once since there was no change in fuels over this short time period. With this data, custom fuel models were

created using the NEWMDL program of the BEHAVE fire behavior prediction system. Since shrub fuels were sparse on all units, their loading was not included in the custom fuel models. These models also do not include small conifer regeneration. The predicted surface fire behavior of these models was computed using the FIRE1 module of BEHAVE, under typical summer wildfire conditions: fine fuel moisture 4%, 20-foot windspeed 20 mph (upslope), slope 15%, herbaceous fuel moisture 50% (live and dead average). However, all custom fuel models for the treatment units indicated predicted surface fire flame lengths of about 1 foot, far less than one would reasonably expect. One reason is that the current fire behavior prediction system is very sensitive to fuel descriptors that are very difficult to measure, such as fuel bed depth and bulk density (Burgan 1987). The 13 standard fire behavior fuel models have been adjusted so that the predicted fire behavior responds reasonably over a range of environmental conditions. In building custom fuel models for the treatment units this adjustment cannot be made since such adjustment requires empirical knowledge of actual fire behavior in each particular fuel type. Since predicting fire behavior on each unit from custom fuel models is outside the scope of existing fire behavior prediction models, treatment implications for fire behavior have been made by examining the changes on fuel quantity after treatment, and by examining changes in crown fuels.

For fire modeling purposes, all treatment units have similar surface fuel complexes and are best described by Fuel Model 2, "Timber, Grass and Understory" (Burgan and Rothermel 1984). This fuel type is capable of producing flame lengths up 8 feet under typical wildfire conditions, as predicted using BEHAVE.

Table 4 shows the load (tons/acre) of surface fuel by class and component for each treatment unit, both before and after treatment. Treatments 2 and 3 showed significant increases in herbaceous fuel (18.2 and 19.4 percent), probably due the lower residual basal area than treatment 1 and greater degree of scarification from logging (and burning on treatment 3). Treatment 1 showed a 10.5 percent decrease in herbaceous fuel load, which is not to be expected in general. It is likely that there was simply no significant change in herbaceous fuel in treatment 1. Herbaceous fuels can contribute to increased flame lengths and rates of spread. However, increasing herbaceous matter is

often one goal of restoration treatments, so changes in this fuel component have positive implications for restoration but negative implications for fire hazard reduction.

Needle litter was reduced in all treatments, most significantly in treatment 3, which was broadcast burned. Even after needle-fall from scorched and fire-killed trees was added back, treatment 3 still showed a net decrease of 41.5 percent over the initial load. Treatments 1 and 2 showed decreases of 11.2 and 19.5 percent, respectively. Needle litter, like herbaceous matter, can contribute significantly to fire behavior, so reduction of needle litter loading generally reduces fire hazard. There may also be positive implications for nutrient cycling, especially in the broadcast burned unit.

The fine fuels (1-hr timelag class) also play a significant role in determining fire behavior. This fuel component was reduced in all treatment units: 26.1 percent in unit 1, 56.0 percent in unit 2, and 86.5 percent in unit 3. Again, the broadcast burn in unit 3 led the high reduction in this fuel component. Like needle litter, reduced loads of 1-hr class fuels generally indicates reduced fire hazards.

The coarser 10-hr timelag fuels (1/4 to 1 inch in diameter) can also contribute to fire behavior, especially if present in significant quantity after a harvest operation. Most branchwood falls into this class, so the presence of logging slash usually indicates quantities of this class. Moreover, the longer burnout time of this size of fuel can lead to increased damage to trees and may initiate passive crowning. Ten-hour class fuels were increased in treatments 1 and 2 but reduced in treatment 3. Again, the broadcast burn in treatment 3 is responsible for the 36.1 percent reduction. Not only was most of the logging slash in this size consumed, but apparently much of the existing 10-hr fuels were consumed as well. Treatments 1 and 2 showed 34.6 and 97.3 percent increases in 10-hr fuel loading. Slash disposal in unit 1 was hand-pile burning, so the increase is probably from logging slash which did not get piled by was left to decompose on the forest floor. In unit 2, the trees were skidded out to a landing in full-tree lengths. Some of the branches are knocked off the bole during skidding, especially if the trees are skidded next to a standing tree. There was no follow-up treatment to reduce these fuels, which are often concentrated at the base of a tree rubbed by the trees being skidded.

Large branches, small tree boles and the tops of harvested trees make up the bulk of the 100-hr timelag class (1 to 3 inches in diameter). Treatments 1 and 3 showed an increase in loading of this size class, of 28.5 and 41.8 percent respectively. This size class is not readily consumed by a prescribed fire, so the increase in treatment 3 comes from the slash which was back-hauled but was not consumed in the fire. Sub-merchantable trees which were knocked over in the harvest also contribute to increases in this component. In treatment 1 the increase is attributable to the same sources, but hand-pile burning disposed of some of the 100-hr fuels created during the harvest. Unit 2 showed a 30 percent decrease in this fuel load. Very little of this size material would have been knocked off the harvested trees during felling or skidding, so there would have been little of this material added. However the existing fuels were probably just rearranged by the disturbance of logging equipment. Some of the existing fuels were probably converted to "duff" after being crushed under the weight of logging machinery. This size of fuel has little bearing on the spread and intensity of a surface fire, but may contribute to increased mortality, and may lead to torching of individual trees.

Woody material larger than 3 inches in diameter is considered 1000-hr timelag fuels. These fuels do not contribute much to the spread and intensity of a surface fire, but the heat evolved in their combustion may increase fire damage and mortality and may lead to torching of individual or groups of trees. This size of woody debris is increasingly recognized as important for maintaining soil productivity and wildlife habitat. However, the presence of slash, especially this size class, reduces the visual quality of a forest stand. If close utilization practices are followed, logging usually adds little to this size class. Much of this size class is rotten or partially rotten and is therefore easily converted to "duff" if crushed by logging equipment. All three treatments showed decreases in both sound and rotten 1000-hr fuels. In unit 1 the reduction is most directly attributable to close utilization of harvested trees and an effort to hand-pile and burn much of the downfall present in the unit before treatment. In units 2 and 3, whole tree skidding meant that almost none of this material was added to the fuel complex. Existing fuels were probably crushed by logging equipment or, in unit 3, consumed in the fire.

Duff was increased in units 1 and 2 and decreased in unit 3. The unit 3 decrease (15.4 percent) is most likely a result of the broadcast burn, which was conducted in the early fall when the duff is dry and readily consumed. The 34.3 percent increase in unit 2 may be a result of conversion of 100- and 1000-hr fuels by crushing. The small 6.2 percent increase in unit 1 probably results from some "conversion crushing", and minimal ground disturbance.

Small conifers are a very important fuel component in these forests. Their relative contribution to fire behavior is far exceeded by their fuel loading. Small trees, especially Douglas-fir, represent a fuel "ladder" that allows a surface fire to reach into the canopy, significantly increasing fire intensity and resistance to control. The broadcast burn in unit 3 removed all small trees at the sample points (some small trees can still be found throughout the unit). In unit 1, 81.8 percent of the small trees were killed, either incidentally through logging damage or intentionally during the slash clean-up phase of logging. Unit 2 showed a 54.5 percent decrease in small trees, all attributable to incidental logging damage. Any treatment designed to reduce fire hazard must reduce the ladder fuels that small trees represent.

#### Crown Fire

The likelihood that a surface fire will become a crown fire is inversely proportional to the foliar moisture content and the height to the base of the tree crowns. Crown fire probability is directly proportional to bulk density of fine crown fuels. Alexander (1988) has provided some guidelines based on Van Wagner's (1977) theoretical crown fire initiation model. Using the stand structure data gathered for each plot, the critical fireline intensity (flame length) necessary to initiate a crown fire was computed following Alexander (1988) and is shown in Table 5. A foliar moisture content of 105% is used for all units.

In the untreated unit 4, height to the base of the live crown averages 28.9 feet. This translates to a critical fireline intensity of 106.3 BTU/ft/s, or 3.8 foot flame lengths. This means that torching or crowning is likely if the surface fire is generating flames longer than 3.8 feet. In the Van Wagner (1977) analysis, some amount of ladder fuel is assumed to be present <sup>in</sup> order to provide ignition in the crowns. If the surface fire rate



of spread exceeds the minimum for unit 4 of 116 ft/min, then the fire will be an active crown fire, with the surface fire and crown fire moving as one vertically-continuous fire front.

By comparison, the critical fireline intensities are higher for the treated units, meaning that a more intense surface fire is required in order to initiate torching or crowning. Treatment 3 would require flames at least 4.6 feet long, Treatment 1 would experience torching with flames of 4.4 feet, and treatment 2 with flames of 4.3 feet. Again, these critical minimum flame lengths assume the presence of ladder fuels to produce local flareups which can ignite the pre-heated crowns. These treatments significantly reduced the quantity of ladder fuels, especially treatment 3 with the broadcast burn. Assuming the critical flame length is exceeded in each unit, the critical minimum surface fire rate of spread is 216 feet/min for unit 2, 191 feet/min for unit 3 and 152 feet/min for unit 1. These are all very high rates of spread for the surface fuels present.

## **Economics**

One objective of this study was to determine the cost feasibility of the different treatments--that is, whether the treatments will pay for themselves. The sole source of revenue from the treatments comes from the sale of logs to local sawmills. Pulpwood and/or firewood was also removed from all units, but these products usually only pay enough to cover harvesting cost and do not provide additional income to offset other treatment costs. The total revenue per acre that can be expected from these treatments is the volume harvested per acre times the appropriate stumpage price.

Stumpage price is determined by subtracting the logging cost (stump-to-mill) for each treatment from the average mill-delivered log price, weighted to account for different species mix if necessary. Mill-delivered log prices are tabulated for each treatment in Table 6. Only two species, ponderosa pine and Douglas-fir, were harvested in these units. The last available log price report (fourth quarter of 1995) published by the Bureau of Business and Economic Research at the University of Montana indicated prices of \$373/MBF for young pine and \$434/MBF for Douglas-fir. These prices

represent the average of sawlog and veneer log prices. Although the total volume harvested per acre varies considerably, the species composition is quite similar, ranging from 47 to 52 percent pine (average 49 percent). This translates to little variation in mill-delivered log prices (ranging from \$402 - \$405/MBF). Because this variation between treatment units is small the overall weighted-average log price of \$404/MBF will be used for all treatments.

Volume harvested per acre, delivered-log prices, logging cost and additional costs such as slash treatment is tabulated in Table 7. Logging cost includes the cost of hauling the logs 40 miles to the mill. Logging cost in units 2 and 3 were identical because the same harvest method was prescribed. These harvest costs were estimated from data in Keegan and others (1995). Logging cost in Unit 1 was higher because a more labor-intensive method was used. Each treatment had additional costs, mostly relating to slash disposal. These costs were estimated by the contractor or taken from the USFS timber sale papers. The slash and some existing dead and down fuels on Unit 1 were disposed of by burning in small hand-built piles at a cost of \$462, or \$77/acre. The landing slash pile on treatment unit 2 was burned at a cost of \$20, or \$3.33/acre. Treatment Unit 3 was broadcast burned in the fall to reduce logging slash, reduce fire hazard, and restore a vigorous understory. The burn was conducted by the USFS Ninemile Ranger District (in coordination with the University of Montana and the Intermountain Fire Sciences Laboratory) at a cost of \$1600, or \$267/acre.

The net revenue of each of the treatments is tabulated in Table 7. All treatments produced a positive net revenue, meaning that they all generated more income than expenses.

## DISCUSSION

### Visual Quality

Photo preference (Triad) and other analyses indicate a slight preference for Treatment 1, due largely to the nearly complete clean-up of slash and the retention of many large trees after harvest. Treatment 5, an unharvested pine stand which was burned intensely then salvage-logged, was consistently ranked lowest in visual quality. Treatment 2 was ranked second. Interestingly, both treatments 1 and 2 were preferred over the unharvested stand. A common perception is that untreated stands will be ranked highest. Treatment 3, which included a broadcast burn, was ranked lower than the control by the Triad study. The presence of bark char<sup>r</sup> may have a negative influence on visual preference.

The intransitivity of the preferences indicates that preferences are not strong, and that differences between treatments may not be significant. Benson (1996) concludes that all treatments were similar in appearance, and apparently viewers did not detect any features that strongly influenced their preference.

### Potential Fire Behavior

All three treatments appear to have reduced the wildfire hazard over the pre-treatment condition. The most hazardous fuel components are the fine fuels (1-hour timelag class, herbaceous, and needle litter), ladder fuels and crown fuels. All treatments reduced the needle litter loading, but herbaceous loading increased in units 2 and 3 due to the increase in sunlight and water availability, and to the soil disturbance. While this fuel increase may tend to produce higher fire intensities when dry, herbaceous matter may also be important in overall forest health and forest aesthetics. All treatments reduced the fine fuel component (1-hr fuels), although only the broadcast burned unit 3 showed a decrease in 10-hr fuels. Small trees which represent ladder fuels were reduced in all treatments, especially unit 3. Live crown base height was higher in all treatment units than in the control unit. The highest post-treatment live crown base heights (LCBH) were found in the broadcast burned unit, where crown scorch probably helped remove some low-hanging live branches.

Post-treatment crown bulk densities were reduced in all treatments. They were reduced most in unit 2 which was thinned from above (hence some large-crowned trees were removed) and least in unit 1, which was only lightly thinned from below. In all cases the minimum fireline intensity (hence flame length) required to heat the crown to combustion temperature was increased in all treatments. Since this critical value is largely a function of LCBH the greatest change was in unit 3, which had the highest residual LCBH. The minimum critical rate of spread was also increased in all treatments. The critical rate of spread is inversely proportional to crown bulk density, so the change in this critical value was greatest in unit 2, which had the least dense crown layer after treatment.

Though all treatments were effective in reducing hazardous fuels, treatment 3 was certainly the most effective because of the broadcast burn. This unit has the highest LCBH, the most-reduced fine fuels, and the most-reduced ladder fuels. The increase in herbaceous fuel is more than offset by these other changes.

## **Economics**

As indicated in Table 7, all treatments are cost-feasible since they are expected to generate more income than expenses at the reported level of log prices. Treatment costs are relatively stable, climbing incrementally each year as the cost of labor, capital, fuel, etc. increases. The price of logs, however, fluctuates widely with changing supply and demand for lumber and logs. A treatment with low fixed costs, like treatment 2, will become revenue-neutral only when log prices drop to nearly the logging cost. A treatment with high fixed costs, like the cost of the broadcast burn in treatment 3, becomes revenue-neutral at much higher prices. To recover the \$267/acre cost of the burn average log prices must be at least \$275/MBF. To pay for the labor-intensive hand-piling in treatment 1 prices must be at least \$245/MBF. Fortunately, log prices are expected to exceed these minimums.

In judging the revenue producing quality of the three treatments one can rank them based on the expected net revenue per acre. Treatment 2 generates the highest net revenue per acre because it has the highest volume harvested, the cheapest slash

treatment, an inexpensive logging method, and no additional treatments. Treatment 2 produces 4.3 times as much net short-term revenue per acre as treatment 1 because treatment 1 has a very low harvest volume, a more expensive logging method and a moderately expensive slash disposal method. Treatment 2 produces 2.32 times as much net revenue as treatment 3 because treatment 3 has less volume per acre and a very expensive slash treatment. The cost of the broadcast burn is high largely due to the relatively small (6 acres) unit. Larger units with similar fuels can be burned at a much lower cost per acre.

It must be noted that the net revenue reported in table 7 represent only the immediate-term monetary benefits. Treatments 1 and 3 removed less volume in this entry and therefore have more residual growing stock than treatment 2. Therefore, the value of the residual timber on treatment 2 will be less than that of the other treatments. Moreover, the lighter treatments, especially treatment 1, can sustainably be treated again sooner and more frequently than treatment 2. The real differences in long-term net revenue derive not from the volume per acre of harvest but from the logging cost and cost of additional treatments such as burning. Another long-term difference between treatments could result from different treatment effects on the long-term forest productivity, which was not measured in this study.

In summary, all of the treatments demonstrated will generate more income than expenses at levels of log prices we can expect in the near future.

## CONCLUSION

This project has demonstrated several alternative thinning methods to reduce forest fire hazard and improve forest health in aesthetically-sensitive residential and recreational forests. All of the treatments developed in this study seem to be appropriate for reducing fire hazard in a sensitive and cost-effective manner. Although the treatments are quite similar in design and implementation, there are differences between them, both significant and subtle, which make them appropriate in different situations.

**Treatment 1: Minimum Impact** This treatment is highly favored for its aesthetic quality, being preferred over not only the other treatments, but over the untreated stand as well. The treatment was moderately effective in reducing fire hazard by reducing fine fuels, raising the LCBH, removing ladder fuels and spacing tree crowns. Although this treatment produced significantly less net income than the others (Table 7), it nonetheless more than paid for itself, providing a return of \$246/ac to the landowner. This treatment is favored on small private residential properties where aesthetic values are high and too-low stand densities are avoided for privacy reasons. The Forest Service may find such a treatment useful in areas with very high recreational values in which there is significant public concern over too much harvesting.

Suggested or possible changes to this treatment include a lower residual stand density, perhaps of about 85 sq. ft. per acre, if the thinning is still done from below, leaving the largest, healthiest trees. The aesthetic acceptance of this treatment is probably derived from the nature of the thinning (from below), but also from the intensive logging and slash disposal methods. A broadcast burn could probably be implemented in this treatment without significant degradation of aesthetic quality if it is conducted after the slash fuels have been disposed of. A burn conducted in slash fuels would likely result in too much bark char or mortality. The additional cost of the burn may make the treatment unable to pay for itself.



**Treatment 2: Generate Short-term Income** This treatment was certainly effective at its emphasis of providing income. It produced more income than the other treatments (Table 7) and was effective at reducing the fire hazard by thinning the overstory, and ranked high aesthetically. This type of treatment is appropriate on a wide range of public and private land.

There is little that could be changed in this treatment to improve its effectiveness. Additional slash treatments such as a broadcast burn could not be justified in light of the income-producing emphasis. Mechanized logging equipment should consistently provide the most cost-effective harvesting in this forest type. Any further reduction in basal area would probably produce an unacceptable aesthetic condition, especially since the thinning is from above. Care must be exercised when implementing a high thinning to avoid "high grading". The goal of a high thinning is to leave a high-quality stand of trees by thinning in the dominant and co-dominant crown classes.

**Treatment 3: Forest Health** This appears to represent a middle ground treatment that balances aesthetics, income production and forest health -- truly an "ecosystem management" treatment with broad application. Any treatment which couples a low thinning with a broadcast burn will significantly reduce wildfire hazard; the data show that this treatment was certainly the most effective of the three in reducing fire hazard. Even with the high cost of the broadcast burn this treatment showed a modest return per acre. Unfortunately, aesthetic quality suffers whenever a broadcast burn chars the boles of trees. This type of thinning and burning treatment has broad applicability on public and increasingly on private lands in the pine type.

Some changes in this could be made to improve this treatment. In this implementation, slash was back-hauled from the landing and spread with the grapple skidder in order to retain as much of the nutrient base on the forest floor as possible. While this practice may have long-term benefits for forest productivity, when coupled with a prescribed burn the increased fuel loads may lead to increased fire-caused mortality, bark char and crown scorch, with negative implications for aesthetics. It may be more practical to dispose of the landing slash in a landing pile and broadcast burn the

natural fuel bed with the small amount of slash left after a mechanized logging operation. The residual basal area could probably also be reduced slightly, bringing in more income and perhaps helping to create more "natural" conditions, without adversely effecting stand aesthetics.

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Figure 1.  
Map of Study Area location,  
Missoula County, MT.

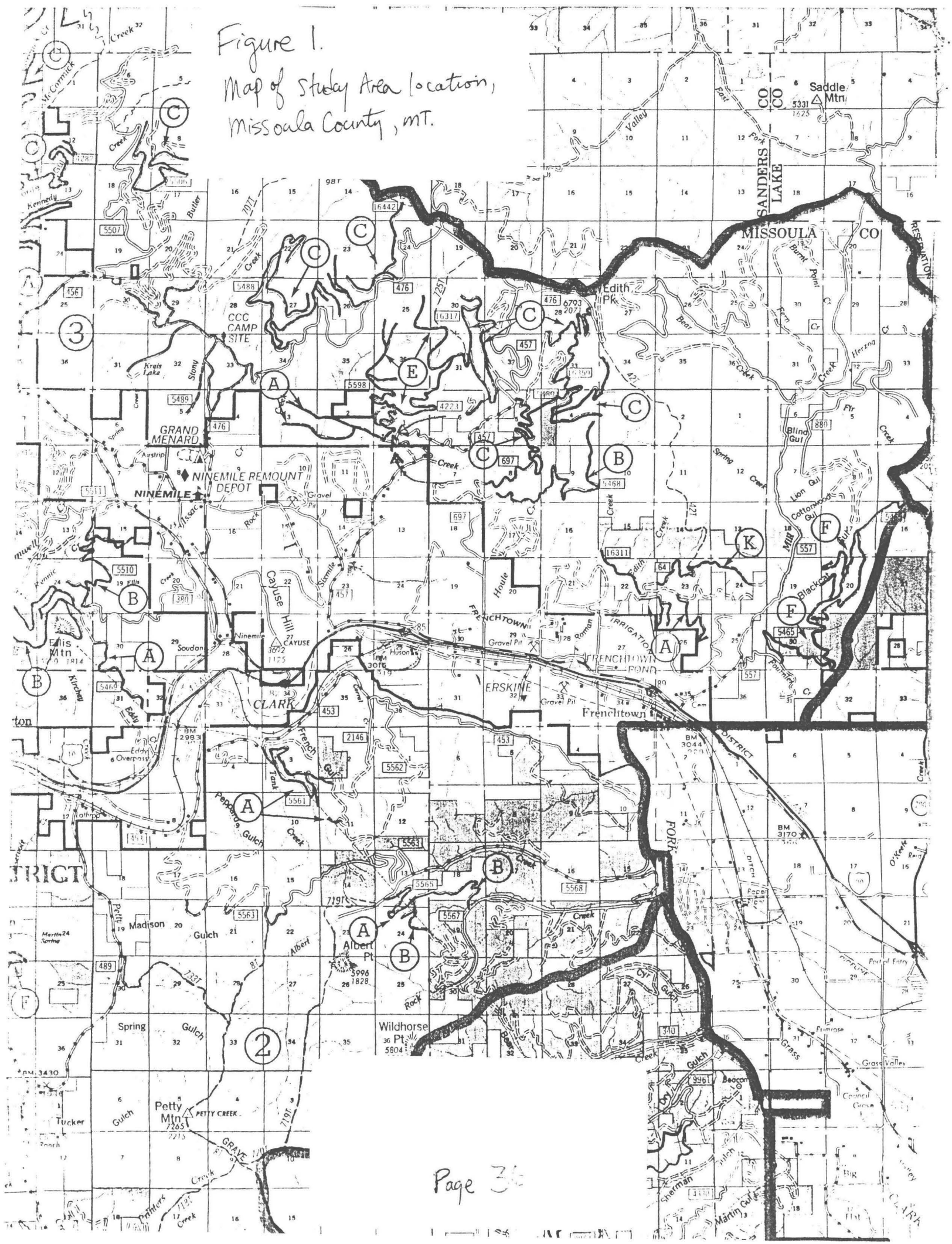
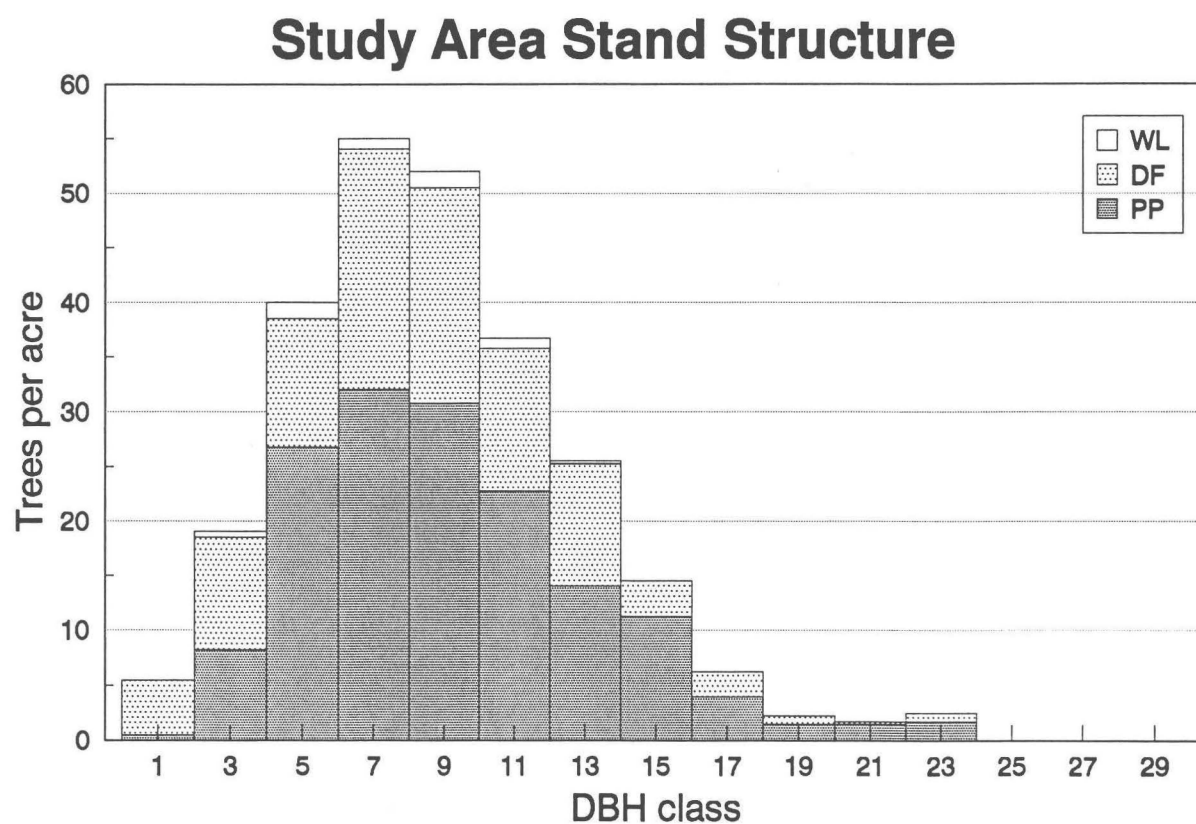


**Figure 2** Stand structure of study area. Diameter distribution and basal area by species for all treatment units, before treatment.



Basal area (sq. ft. per acre)

PP 89

DF 49

WL 2

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TOT 140



**Figure 3** Location of units within study area. All units are in Township 15 North, Range 22 West. Units 1, 2 and 3 are in section 1; unit 4 is in Section 2.

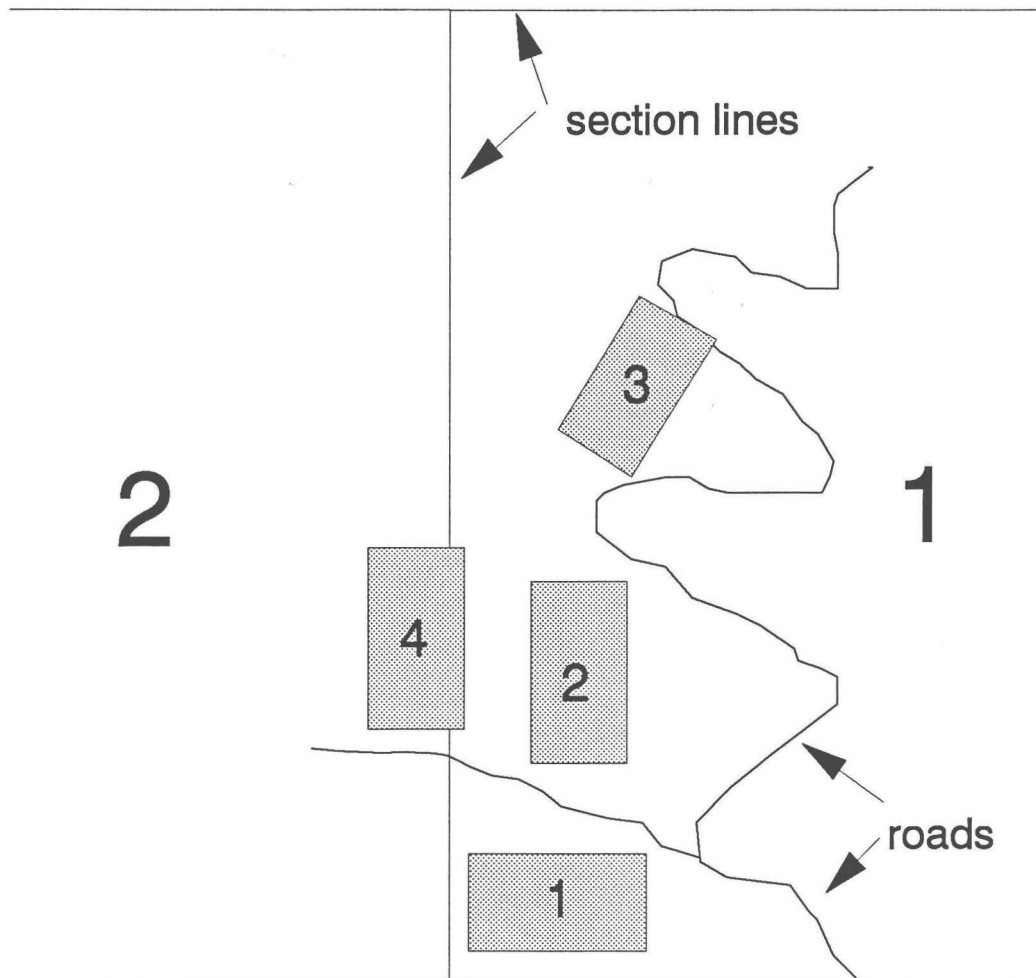


**Figure 4** Location of permanent sample points within each unit.

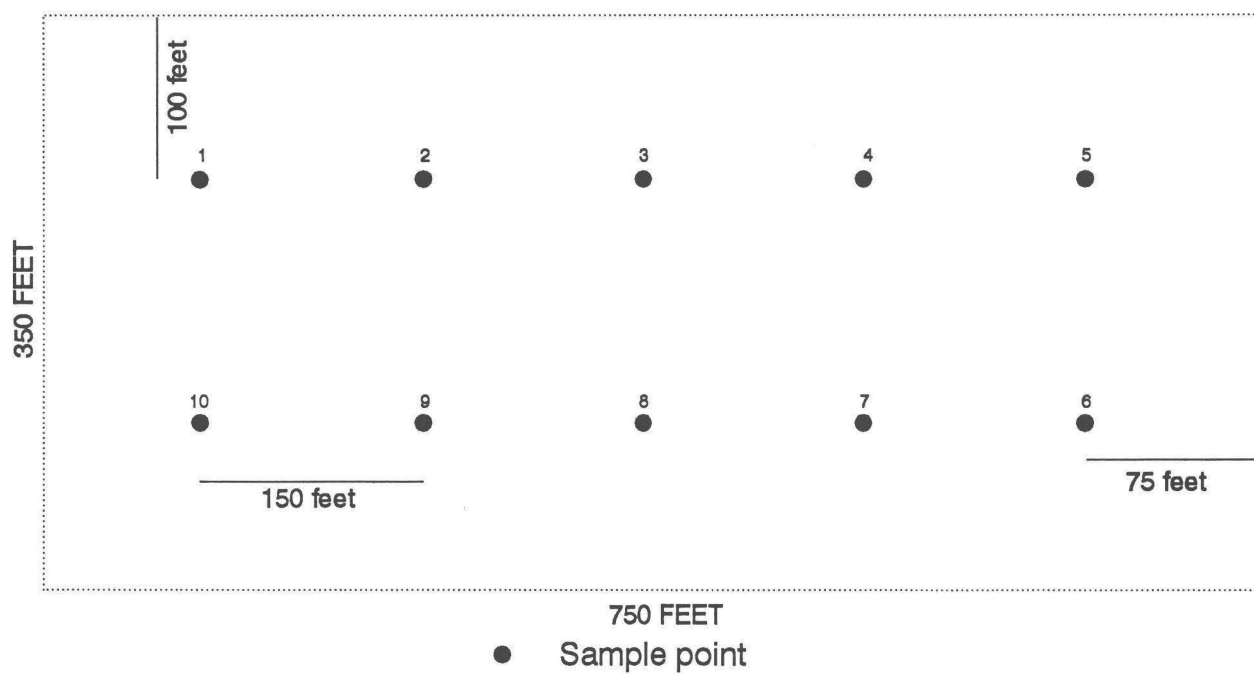


**Figure 5** Design of sample point.

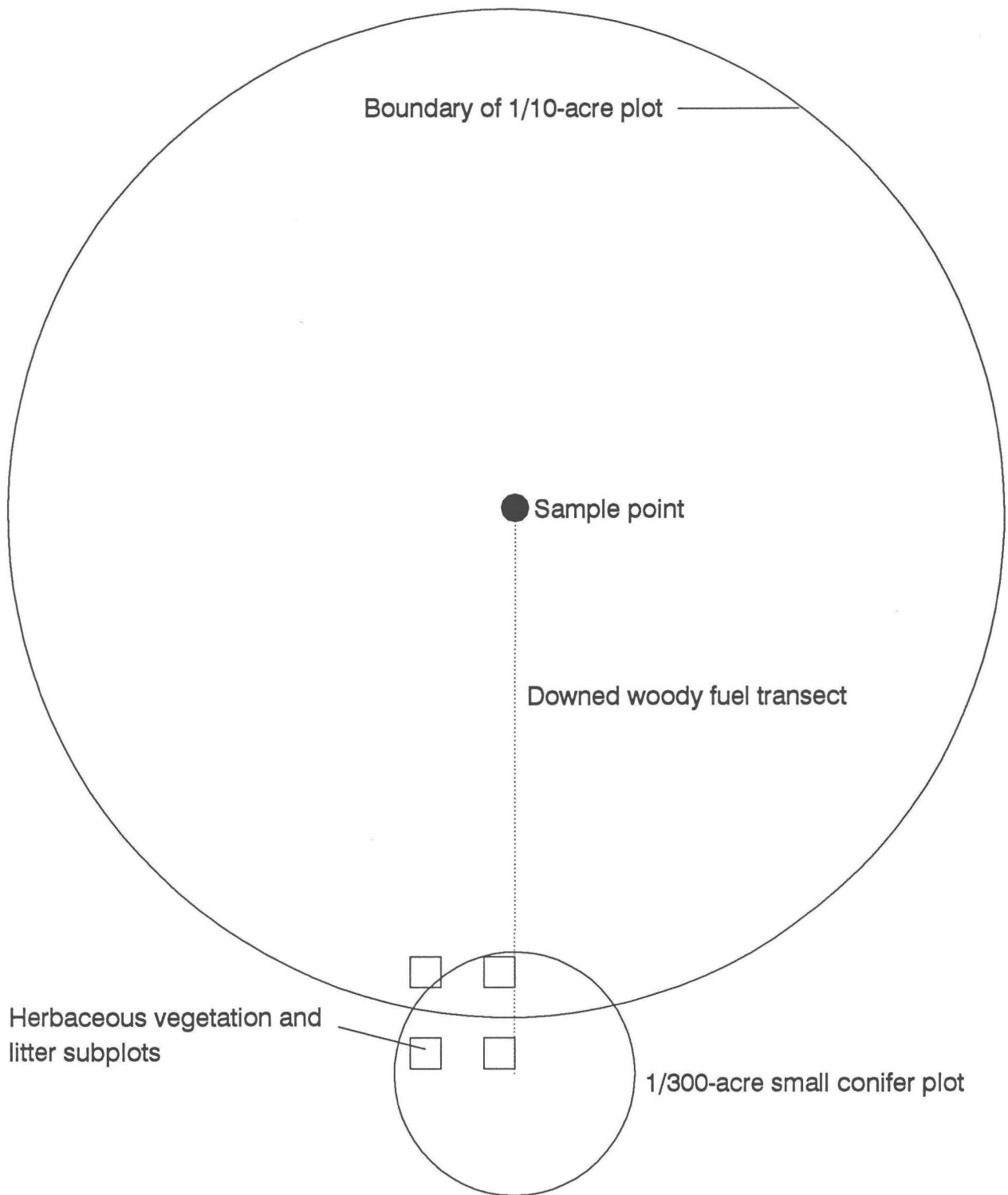


**Figure 6** Layout of permanent photo points.

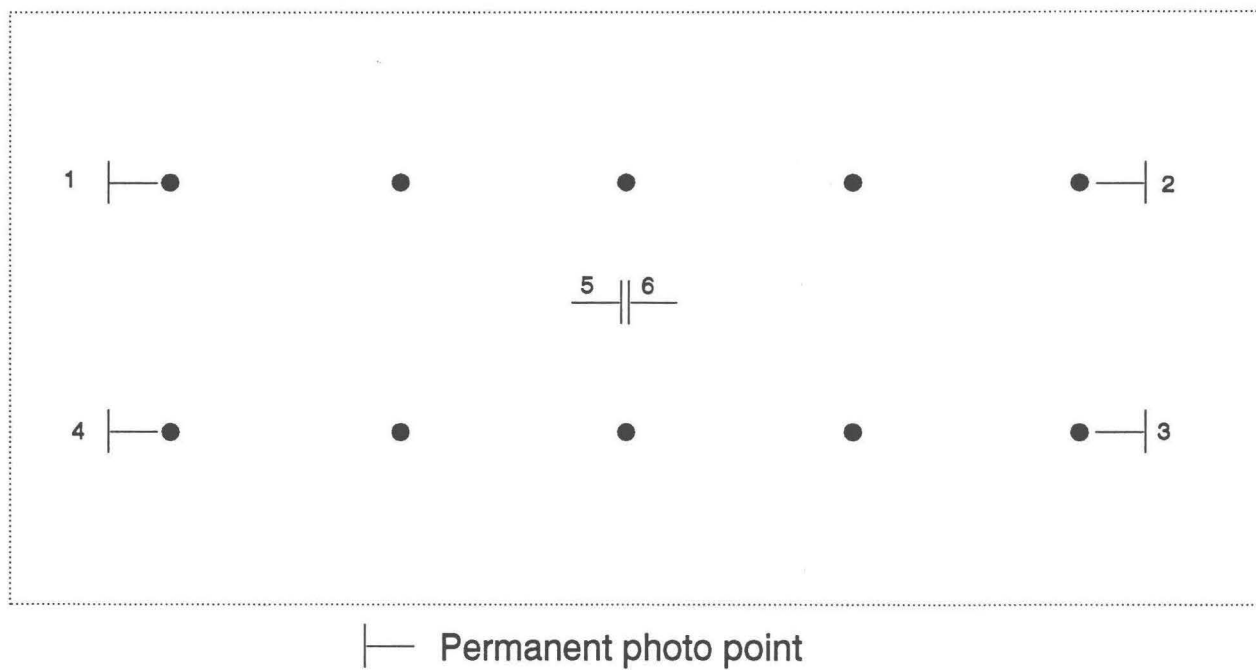


**Table 1** Orientation of fuel transects.

| Sample Point | True Azimuth |
|--------------|--------------|
| 1            | 0            |
| 2            | 36           |
| 3            | 72           |
| 4            | 108          |
| 5            | 144          |
| 6            | 180          |
| 7            | 216          |
| 8            | 252          |
| 9            | 288          |
| 10           | 324          |

**Table 2** Measures of stand density before and after treatment.

| UNIT | Basal area<br>(sq. ft./ac) |      | Trees per acre<br>(TPA) |      | Average stand DBH<br>(in.) |      |
|------|----------------------------|------|-------------------------|------|----------------------------|------|
|      | PRE                        | POST | PRE                     | POST | PRE                        | POST |
| 1    | 137                        | 94   | 266                     | 125  | 9.6                        | 11.8 |
| 2    | 137                        | 69   | 263                     | 99   | 10.2                       | 11.4 |
| 3    | 145                        | 76   | 266                     | 78   | 10.4                       | 13.3 |
| 4    | 150                        |      | 249                     |      | 10.5                       |      |



**Table 3** Summary of damage to trees one year after treatment.

| Unit | Logging scars (%) |       |        |       | Bark char (%) |       |        |       | Bark beetle attack (%) |       |        |       |
|------|-------------------|-------|--------|-------|---------------|-------|--------|-------|------------------------|-------|--------|-------|
|      | None              | Small | Medium | Large | None          | Light | Medium | Heavy | None                   | Light | Medium | Heavy |
| 1    | 100               | 0     | 0      | 0     | 99.2          | .8    | 0      | 0     | 90.4                   | 7.2   | 1.6    | .8    |
| 2    | 75.8              | 12.1  | 9.1    | 3     | 100           | 0     | 0      | 0     | 95                     | 4     | 1      | 0     |
| 3    | 73.1              | 12.8  | 9      | 5.1   | 6.4           | 24.4  | 51.3   | 18    | 88.5                   | 6.4   | 3.9    | 1.3   |
| 4    | 100               | 0     | 0      | 0     | 100           | 0     | 0      | 0     | 98.8                   | .4    | .4     | .4    |

**Table 4** Fuel loading by component and class.

|                | Unit 1 |       |        | Unit 2 |       |        | Unit 3 |       |        | Unit 4 |
|----------------|--------|-------|--------|--------|-------|--------|--------|-------|--------|--------|
| Component      | PRE    | POST  | % CHNG | PRE    | POST  | %CHN G | PRE    | POST  | % CHNG |        |
| Herbaceous     | .19    | .17   | -10.5% | .22    | .26   | 18.2%  | .31    | .37   | 19.4%  | .10    |
| Needle litter  | 1.25   | 1.11  | -11.2% | 1.18   | .95   | -19.5% | 1.18   | .69   | -41.5% | 1.16   |
| 1-hr           | .23    | .17   | -26.1% | .42    | .19   | -56.0% | .41    | .06   | -86.5% | .27    |
| 10-hr          | .89    | 1.19  | 34.6%  | 1.13   | 2.23  | 97.3%  | 1.53   | .98   | -36.1% | .92    |
| 100-hr         | 1.02   | 1.31  | 28.5%  | 1.46   | 1.02  | -30.0% | 1.03   | 1.46  | 41.8%  | .58    |
| 1000-hr sound  | 5.32   | 1.64  | -69.2% | 4.03   | .80   | -80.1% | 6.15   | 4.69  | -23.8% | 3.76   |
| 1000-hr rotten | 1.67   | .69   | -58.8% | 1.49   | .89   | -40.1% | 2.77   | .33   | -88.1% | 3.49   |
| Duff           | 17.1   | 18.2  | 6.2%   | 15.9   | 21.3  | 34.3%  | 17.7   | 15    | -15.4% | 17.7   |
| Small trees    | .11    | .02   | -81.8% | .11    | .05   | -54.5% | .07    | 0     | -100%  | .09    |
| Total          | 27.76  | 24.45 | -11.9% | 25.93  | 27.72 | 6.9%   | 31.15  | 23.54 | -24.4% | 28.06  |

**Table 5** Crown fire initiation parameters.

|                                                     | Treatment 1 | Treatment 2 | Treatment 3 | Untreated |
|-----------------------------------------------------|-------------|-------------|-------------|-----------|
| Foliar Moisture Content, percent                    | 105         | 105         | 105         | 105       |
| Live Crown Base Height, ft                          | 34.1        | 32.2        | 36.4        | 28.9      |
| Crown Bulk Density, lbs/cu. ft.                     | .0040       | .0028       | .0032       | .0061     |
| Critical values required for crown fire initiation. |             |             |             |           |
| Fireline Intensity, BTU/ft/s                        | 145         | 136.9       | 154.7       | 106.3     |
| Flame length, ft                                    | 4.4         | 4.3         | 4.6         | 3.8       |
| Rate of Spread, ft/min                              | 152         | 216         | 191         | 116       |

**Table 6** Delivered log prices by species and species mix for each treatment, fourth quarter 1995. Delivered log prices for ponderosa pine and Douglas-fir represent the average of sawlog and veneer log prices.

| Unit | Harvest volume<br>MBF/ac (percent) |              | Delivered log prices |           | Weighted average<br>log price |
|------|------------------------------------|--------------|----------------------|-----------|-------------------------------|
|      | PP                                 | DF           | PP                   | DF        |                               |
| 1    | .849 (49.7%)                       | .860 (50.3%) | \$373/MBF            | \$434/MBF | \$404/MBF                     |
| 2    | 2.44 (46.7%)                       | 2.78 (53.3%) |                      |           | \$405/MBF                     |
| 3    | 1.86 (52.3%)                       | 1.70 (47.7%) |                      |           | \$402/MBF                     |
| 4    | N/A                                | N/A          |                      |           | N/A                           |
| ALL  | 1.72 (49.1%)                       | 1.78 (50.9%) |                      |           | \$404/MBF                     |

**Table 7** Net revenue per acre from the different treatments. Delivered log value was determined from the prices of individual species and the average species mix from all treatments (see Table XXXX).

| Unit | Harvest volume (MBF/ac) | Delivered log value (\$/MBF) | Logging cost stump to mill (\$/MBF) | Additional treatments (\$/ac) | Net revenue (\$/ac) |
|------|-------------------------|------------------------------|-------------------------------------|-------------------------------|---------------------|
| 1    | 1.708                   | \$404/MBF                    | \$215/MBF                           | \$77/ac                       | \$246/ac            |
| 2    | 5.228                   |                              | \$200/MBF                           | \$3.33/ac                     | \$1067/ac           |
| 3    | 3.557                   |                              | \$200/MBF                           | \$267/ac                      | \$459/ac            |
| 4    | 0                       |                              | N/A                                 | N/A                           | \$0/ac              |